FULL-CLOSED CONTROL APPARATUS

BACKGROUND OF THE INVENTION

1.Field of the Invention

The present invention relates to a full-closed control apparatus for performing position control based on a position signal of a load driven by a motor.

2.Description of the Related Art

Generally, full-closed control for performing speed control based on a speed signal of a motor and performing position control based on a position signal of a load driven by the motor is required for accurate positioning. If rigidity in coupling the motor and the load to each other is low, it is however impossible to achieve high-speed control by ordinary full-closed control. This is because a control system vibrates at a frequency near an antiresonance frequency of a mechanical system when the gain of a position controller is increased, that is, because the upper limit of the gain of the position controller becomes lower than that in semi-closed control. To solve this problem, the present applicant has proposed a full-closed control apparatus shown in Fig. 5 in Japanese Patent OPI publication No. 2001-309676.

In Fig. 5, the reference numeral 1 designates a motor-including mechanical system which has an equivalent rigid model 5, a mechanical resonance system 6, a load principal vibration system 7, and an integration 8. Incidentally, J is inertia of a movable portion of the mechanical system, D is a coefficient of viscous friction of an equivalent rigid system, ω_r is an angular frequency of resonance, ζ_r is a viscosity coefficient of resonance, ω_a is an angular frequency of antiresonance, and ζ_a is a viscosity coefficient of antiresonance. The reference numeral 2 designates a load vibration suppression compensator which has an amplitude adjuster 9, and a band-pass filter 10. The reference numeral 3 designates a position controller. The reference numeral 4 designates a speed controller. A

difference signal E_L obtained by subtracting a load position signal X_L from a position command X_r is multiplied by a position control gain K_p to thereby obtain a speed command basic signal V_{rb}. A difference signal obtained by subtracting a speed command V_r from a load speed signal V_L is input into the band-pass filter 10. An output of the band-pass filter 10 is input into the amplitude adjuster 9. A signal obtained by adding a speed command compensatory signal V_{rh} as an output of the amplitude adjuster 9 to the speed command basic signal V_{rb} is set as a new speed command V_r. A difference signal obtained by subtracting a motor speed V_m from the speed command V_r is input into the speed controller 4. An output of the speed controller 4 is set as a torque command T_r. The motor-including mechanical system 1 is driven on the basis of T_r.

In the related art, if the gain of the speed controller is sufficiently high, the gain of the equivalent rigid system speed loop model is approximately equal to 1 in a low-frequency region. Accordingly, the difference signal V_{Ld} obtained by subtracting the speed command V_r from the load speed V_L can be regarded as an estimated signal of vibration contained in the load speed. When V_{Ld} is phase-adjusted by the band-pass filter and gain-adjusted by the amplitude adjuster to cancel a vibration mode contained in the speed command basic signal, a position loop can be stabilized even in the case where the gain of the position controller is high.

In the related art, however, if the gain of the speed controller cannot be increased so sufficiently, the gain of the equivalent rigid system speed loop model is lower than 1 in a low-frequency region. For this reason, a low-frequency component is contained in the difference signal V_{Ld} obtained by subtracting the speed command V_r from the load speed V_L. On the other hand, because the band-pass filter is also used as a phase adjuster, a predetermined phase delay is given to the oscillation frequency f_d of the position loop. Accordingly, the center frequency f_0 of the pass band in the band-pass filter becomes lower than the oscillation frequency f_d of the position loop. When, for example, the band-pass filter is constituted by a

combination of a two-stage low-pass filter ($1/(1+T_f s)$) and a two-stage high-pass filter ($T_f s/(1+T_f s)$) in the case where the oscillation frequency f_d of the position loop is 40 Hz, the center frequency f_0 of the pass band in the band-pass filter is 16.6 Hz (Fig. 6) because a phase delay of 90° is given to a point of 40 Hz.

Because the speed command compensatory signal V_{rh} contains a low-frequency component with a large amplitude as described above, there is a problem that low-frequency vibration or overshooting is apt to occur (Fig. 8).

SUMMARY OF THE INVENTION

Therefore, an object of the invention is to provide an apparatus by which the problem in the related art can be solved and by which while the vibration of a position loop can be suppressed, the position control gain can be increased to achieve speedy and accurate positioning.

To achieve the foregoing object, the invention provides a full-closed control apparatus for performing speed control based on a speed signal of a motor and performing position control based on a position signal of a load driven by the motor, including: an equivalent rigid system speed loop model; a band-pass filter; an amplitude adjuster; and a unit for inputting a speed command of a speed control loop into the equivalent rigid system speed loop model, inputting a difference signal obtained by subtracting an output of the equivalent rigid system speed loop model from a speed signal of the load into the band-pass filter, inputting an output of the band-pass filter into the amplitude adjuster and outputting a signal obtained by adding an output of the amplitude adjuster to an output of a position controller, as a new speed command.

The invention also provides a full-closed control apparatus for performing speed control based on a speed signal of a motor and performing position control based on a position signal of a load driven by the motor, including: an all-pass filter; a band-pass filter; an amplitude adjuster; and a unit for inputting a difference signal obtained by subtracting a speed

command of a speed control loop from a speed signal of the load into the all-pass filter, inputting an output of the all-pass filter into the band-pass filter, inputting an output of the band-pass filter into the amplitude adjuster and outputting a signal obtained by adding an output of the amplitude adjuster to an output of a position controller, as a new speed command.

The invention further provides a full-closed control apparatus for performing speed control based on a speed signal of a motor and performing position control based on a position signal of a load driven by the motor, including: an equivalent rigid system speed loop model; an all-pass filter; a band-pass filter; an amplitude adjuster; and a unit for inputting a speed command of a speed control loop into the equivalent rigid system speed loop model, inputting a difference signal obtained by subtracting an output of the equivalent rigid system speed loop model from a speed signal of the load into the all-pass filter, inputting an output of the all-pass filter into the band-pass filter, inputting an output of the band-pass filter into the amplitude adjuster and outputting a signal obtained by adding an output of the amplitude adjuster to an output of a position controller, as a new speed command.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram showing a first embodiment of the invention.

Fig. 2 is a diagram showing a second embodiment of the invention.

Fig. 3 is a diagram showing a third embodiment of the invention.

Fig. 4 is a block diagram of an equivalent rigid system speed loop.

Fig. 5 is a diagram showing a control system in the related art.

Fig. 6 is a Bode diagram of the band-pass filter depicted in Figs. 1 and 5.

Fig. 7 is a Bode diagram of a phase and gain adjuster constituted by a combination of the band-pass filter and the all-pass filter depicted in Figs. 2 and 3.

Fig. 8 is a graph showing a result of simulation in the related art.

Fig. 9 is a graph showing a result of simulation in the first

embodiment of the invention.

Fig. 10 is a graph showing a result of simulation in the second embodiment of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Specific embodiments of the invention will be described below. Fig. 1 shows a first embodiment of the invention. A control system shown in Fig. 1 is configured by addition of an equivalent rigid system speed loop model 12 to the control system (Fig. 5) in the related art. In Fig. 1, a difference signal V_{Ld} obtained from subtracting an output V_{L0} of the equivalent rigid system speed loop model 12 from a load speed signal V_L is input into the band-pass filter 10. An output of the band-pass filter 10 is input into the amplitude adjuster 9. A signal obtained by adding a speed command compensatory signal V_{rh} as an output of the amplitude adjuster 9 to the speed command basic signal V_{rb} is set as a new speed command V_r.

A principle for suppression of vibration of a position loop will be described below. The equivalent rigid system speed loop model $G_{V0}(s)$ is an input/output transfer function of a closed loop constituted by a combination of a speed controller 4 and an equivalent rigid system 5 as shown in Fig. 4. That is, $G_{V0}(s)$ is given as follows.

[Expression 1]

$$G_{V0}(s) = \frac{C_V(s)\dfrac{1}{Js+D}}{1 + C_V(s)\dfrac{1}{Js+D}} = \frac{C_V(s)}{Js + D + C_V(s)} \qquad (1)$$

When the mechanical system is a rigid system on the assumption that there is neither disturbance nor identification error, V_{Ld} ($= V_L - V_{L0}$) is zero because it is obvious that V_{L0} is equal to V_L. Accordingly, when the mechanical system is an inertial system, V_{Ld} contains no signal but a vibration signal (frequency: f_d) of load speed. When the phase and gain of V_{Ld} are adjusted by the band-pass filter and the amplitude adjuster to cancel a vibration mode contained in the speed command basic signal V_{rb}, the position loop can be stabilized even in the case where the gain of the

position controller is high. Because V_{Ld} contains no low-frequency component, that is, because V_{rh} contains no low-frequency component, addition of the speed command compensatory signal V_{rh} to the speed command basic signal V_{rb} exerts no influence on response characteristic in a low-frequency region. That is, the problem that low-frequency vibration or overshooting is caused by combination of the load vibration suppression compensator can be avoided (Fig. 9).

Fig. 2 shows a second embodiment of the invention. A control system shown in Fig. 2 is configured by addition of an all-pass filter 11 to the control system (Fig. 5) in the related art. In Fig. 2, a difference signal V_{Ld} obtained by subtracting a speed command V_r from a load speed signal V_L is input into the all-pass filter 11. An output of the all-pass filter 11 is input into the band-pass filter 10. An output of the band-pass filter 10 is input into the amplitude adjuster 9. A signal obtained by adding a speed command compensatory signal V_{rh} as an output of the amplitude adjuster 9 to the speed command basic signal V_{rb} is set as a new speed command V_r.

A principle for suppression of vibration of a position loop will be described below.

The gain of the all-pass filter is always 1 though the phase varies according to change in filter parameter and frequency. Because the all-pass filter in this embodiment is used as an exclusive phase adjuster, the band-pass filter need not be used for phase adjustment. Accordingly, the band-pass filter can be configured so that the center frequency f_0 of the pass band in the band-pass filter coincides with the oscillation frequency f_d of the position loop. When, for example, the all-pass filter and the band-pass filter are constituted by a linear filter ($(s-\omega_d)/(s+\omega_d)$, $\omega_d=2\pi f_d$) and a combination of a one-stage low-pass filter ($1/(1+T_f s)$) and a one-stage high-pass filter ($T_f s/(1+T_f s)$) respectively in the case where the oscillation frequency f_d of the position loop is 40 Hz, the center frequency f_0 of the pass band in the band-pass filter is 40 Hz (Fig. 7) because a phase delay of 90° is given to a point of 40 Hz. The linear all-pass filter can be constituted by a

simple low-pass filter represented by the following expression.

[Expression 2]

$$\frac{s - \omega_d}{s + \omega_d} = 1 - 2\frac{\omega_d}{s + \omega_d} \qquad (2)$$

In this manner, even in the case where the gain of the speed controller is low, V_{Ld} (= $V_L - V_r$) contains a low-frequency component. The low-frequency component is however removed by the band-pass filter because the center frequency f_0 of the pass band in the band-pass filter is high as described above. When a signal of a frequency f_d contained in V_{Ld} passes through the all-pass filter and the amplitude adjuster, the phase and gain of the signal are adjusted to cancel the vibration mode contained in the speed command basic signal. Accordingly, when the speed command compensatory signal V_{rh} is added to the speed command basic signal V_{rb}, the vibration of the position loop is suppressed so that low-frequency vibration or overshooting can be avoided (Fig. 10).

A third embodiment of the invention will be described with reference to Fig. 3. A control system shown in Fig. 3 is configured by addition of an equivalent rigid system speed loop model 12 and an all-pass filter 11 to the control system (Fig. 5) in the related art. In Fig. 3, a difference signal V_{Ld} obtained by subtracting an output V_{Lo} of the equivalent rigid system speed loop model 12 from a load speed signal V_L is input into the all-pass filter 11. An output of the all-pass filter 11 is input into the band-pass filter 10. An output of the band-pass filter 10 is input into the amplitude adjuster 9. A signal obtained by adding a speed command compensatory signal V_{rh} as an output of the amplitude adjuster 9 to the speed command basic signal V_{rb} is set as a new speed command V_r.

A principle for suppression of vibration of a position loop will be described below.

For the same reason as in the first embodiment, when there is neither disturbance nor identification error, V_{Ld} contains no signal but a vibration

signal (frequency: f_d) of load speed. For the same reason as in the second embodiment, even when there is disturbance or identification error, all components except the oscillation frequency f_d of the position loop are removed after passing through the band-pass filter. Finally, the vibration of the position loop can be suppressed, so that low-frequency vibration or overshooting can be avoided.

As described above, in accordance with the invention, the vibration signal of the position loop contained in the speed command basic signal is cancelled by the speed command compensatory signal, so that the gain of the position loop can be increased. In addition, because the speed loop model or the all-pass filter is added, low-frequency vibration or overshooting can be avoided. That is, speedy and accurate positioning can be achieved.